AD-762 943

NITROGEN AND HYDRAZINE LEAKAGE OF MONOPROPELLANT ACS VALVES

Garreth J. Gunderson

Air Force Rocket Propulsion Laboratory
Edwards Air Forcc Base, California

April 1973

AFRPL-TR-73-13

AD 762943

NITROGEN AND HYDRAZINE LEAKAGE OF MONOPROPELLANT ACS VALVES

G.J. GUNDERSON, SSGT, USAF

TECHNICAL REPORT AFRPL-TR-73-13

APRIL 1973

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

AIR FORCE ROCKET PROPULSION LABORATORY
DIRECTOR OF SCIENCE AND TECHNOLOGY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS CALIFORNIA

Best
Available
Copy

NOTICES

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Rocket Propulsion Laboratory Edwards CA 93523	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A
3. REPORT TITLE Nitrogen and Hydrazine Leakage of Monopropellant ACS Valves	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report (July 1971 to March 1973)	
5. AUTHOR(S) (First name, middle initial, last name) Garreth J. Gunderson, SSgt, USAF	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1973	73	11

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFRPL-TR-73-13
b. PROJECT NO. 305810RH	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Air Force Systems Command Edwards CA 93523

13. ABSTRACT

This report documents an in-house test program which was conducted by the AFRPL to expand understanding of the gas and liquid leakage flow phenomena associated with monopropellant hydrazine attitude control system (ACS) valves. Over [illegible] gas (nitrogen) and liquid (hydrazine) leakage tests were conducted on two each PARKER-HANNIFIN hard seat, PARKER-HANNIFIN teflon seat and HYDRAULIC RESEARCH AND MANUFACTURING hard seat valves. Analysis of the leakage test data for these particular valves indicates the following:

While nitrogen gas leakage is a strong function of valve inlet pressure, liquid hydrazine leakage is a very weak function of inlet pressure.

Liquid hydrazine leakage exhibits definite tendencies to decrease with valve exposure time to propellant.

Temperature studies to [illegible]°F demonstrated an inverse relationship between valve temperature and nitrogen leak rate.

Cycling studies demonstrated a random leakage variation with each valve actuation but a definite decrease in nitrogen leakage with extended cycling in the hydrazine propellant.

Attempts to establish a well-defined correlation between hydrazine and nitrogen leakage were hindered by the significant liquid leakage variation with time.

Additionally, the utility of a tiny, commercially available rotameter to instantaneously measure small amounts of hydrazine leakage is discussed.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
hydrazine						
nitrogen						
ACS						
valve						
leakage						
correlation						
flowmeter						
cycle						

AFRPL-TR-73-13

NITROGEN AND HYDRAZINE LEAKAGE OF MONOPROPELLANT ACS VALVES

Garreth J. Gunderson, SSgt. USAF

APRIL 1973

AIR FORCE ROCKET PROPULSION LABORATORY
DIRECTOR OF SCIENCE AND TECHNOLOGY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA

ic

FOREWORD

This report was prepared by the Engine Components Branch, Liquid Rocket Division, Air Force Rocket Propulsion Laboratory. The investigation was conducted under Project 30581ORH, "Valve Leakage Correlation Program," from July 1971 to March 1973, with SSgt G. J. Gunderson as Project/Test Engineer. This test program was requested by the Space and Missile Systems Organization (SAMSO) and the Aerospace Corporation. The work described herein completes the current program, the objectives which were threefold:

(1) To demonstrate simple, reliable measurement techniques for valve seat leakage (liquid hydrazine and gaseous nitrogen)

(2) To investigate pressure, temperature and cycling effects on valve seat leakage, and

(3) To establish a correlation between liquid hydrazine leakage and gaseous nitrogen leakage.

This technical report has been reviewed and is approved.

PHIL S. MARTIN, Capt. USAF
Acting Chief, Engine Components Branch
Liquid Rocket Division

ABSTRACT

This report documents an in-house test program which was conducted by the Air Force Rocket Propulsion Laboratory (AFRPL) to expand understanding of the gas and liquid leakage flow phenomena associated with monopropellant hydrazine attitude control system (ACS) valves. Over 800 gas (nitrogen) and liquid (hydrazine) leakage tests were conducted on two (each) PARKER-HANNIFIN hard seat, PARKER-HANNIFIN teflon seat, and HYDRAULIC RESEARCH AND MANUFACTURING hard seat valves. Analysis of the leakage test data for these particular valves indicates the following:

While nitrogen gas leakage is a strong function of valve inlet pressure, liquid hydrazine leakage is a very weak function of inlet pressure.

Liquid hydrazine leakage exhibits definite tendencies to decrease with valve exposure time to propellant.

Temperature studies to 250°F demonstrated an inverse relationship between valve temperature and nitrogen leak rate.

Cycling studies demonstrated a random leakage variation with each valve actuation, but a definite decrease in nitrogen leakage with extended cycling in the hydrazine propellant.

Attempts to establish a well-defined correlation between hydrazine and nitrogen leakage were hindered by the significant liquid leakage variation with time.

Additionally, the utility of a tiny, commercially available rotameter to instantaneously measure small amounts of hydrazine leakage is discussed.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

At the request of the Air Force Space and Missile Systems Organization (SAMSO) this program was conducted to expand the understanding of the gas and liquid leakage flow phenomena associated with monopropellant hydrazine valves.

The prediction and measurement of valve seat leakage in liquid rocket attitude control systems (ACS) is a serious problem and an area of general uncertainty. The complexity of these leakage phenomena increases considerably when realistic valve hardware is being investigated with actual propellants. The difficulties involved in measuring minute amounts of liquid leakage, even at the component level, have resulted in a lack of experimental liquid leakage data on current ACS valve hardware. Without the necessary experimental data needed to effectively characterize gas and liquid leakage through actual valves with actual propellants, standard gas leakage measurement procedures (e.g., with nitrogen gas) are commonly used as the tools for establishing current leakage specifications for ACS valves at the component, subsystem, and system levels. These specifications, thus established, are now suspected to be overly conservative with respect to the actual liquid propellant leakages that they are thought to represent. High valve rejection rates (possibly due to an overly conservative gas spec) or the necessity for replacing or flushing valves already mated to thrusters can considerably increase mission costs.

For this investigation, off-the-shelf valve hardware was to be procured and tested to note pressure, temperature, time, and cycling effects on seat leakage. The valves of interest were applicable to monopropellant catalytic hydrazine ACS thrusters of the five-pound thrust family. The generation of enough liquid and gas leakage correlation data to ultimately provide the basis for establishing more realistic gas leakage criteria for acceptance test purposes was the primary goal of the program.

Several other organizations have made attempts to correlate gas and liquid leak rates (References 1 through 4) and have generated data to that end. Unfortunately, for one reason or another "No generally satisfactory correlation has been found which is accepted by the propulsion community" (Reference 5).

An in-depth discussion of the gas and liquid flow phenomena, with a detailed explanation of the leakage data presented in this report is beyond the scope of this investigation. Consequently, the reader will note that sophisticated analyses of every leakage test in all test series have been carefully omitted. In those cases where explanatory remarks have been made, pertaining to leakage theory and the data observed, they reflect solely the judgment of the author. Since a limited number of tests were made on a small number of valves, application of the results to other hardware of the same or similar design should be done with caution.

In summary, it is hoped that this program has further illustrated the complexity of the valve leakage problem in liquid rocket systems. Some light has been shed on the various approaches which may be used to measure small amounts of valve leakage. For the valves studied, certain temperature, pressure, cycling and time effects have been noted. It is unfortunate that the correlation of liquid to gas leakage, which has been so earnestly sought after, still did not come forth.

SECTION II

APPROACH

The program was divided into five tasks. Task I entailed selection of the particular valves of most interest to SAMSO/AEROSPACE. The selection of the Parker and Hydraulic Research designs was made in light of their availability and the time/funding constraints imposed upon the program. The Task II effort consisted of the selection and qualification of the techniques to be used for measuring gas and liquid leakage. Particular attention was devoted to the study of earlier efforts in this area (References 2 and 3) and the techniques which had been used in those investigations. Having decided upon the methodology to be used for measuring the gas and liquid leaks, Task III of the program entailed incorporation of the selected techniques into a hydrazine flow system. Design, buildup, and checkout of the system with an adjustable micrometer needle valve to simulate tiny leaks was accomplished. In Task IV the actual gas and liquid leakage testing was done. Selected valves from those procured in Task I were installed individually in the test system and observed to note pressure, temperature, cycling and time effects on leakage. The data may be found in Tables I through VIII in Section VI of this report along with a discussion of those results. Program documentation was accomplished in Task V of the program.

SECTION III

TEST VALVE DESCRIPTIONS

PARKER HANNIFIN VALVES

Two varieties (hard seat and teflon seat) of Parker Hannifin solenoid valves were of particular interest to SAMSO due to their current application on an operational USAF system. These particular valves are used to control the flow of hydrazine to a Rocket Research Corporation catalytic engine in the five pound thrust range.

Depicted schematically in Figure 1 (shown with the teflon seat swaged in) the valve is normally closed until the coil is energized. Upon release of power, the stainless steel poppet (17-4 PH) is forced against the seat (either flat lapped 304-L or teflon) and held there by the coil spring and also the upstream pressure force. General operating characteristics of the Parker valve are listed in Table IX.

For this investigation, a total of six Parker valves, each of varying gas leakage characteristics, were procured. Three were of the hard seat variety and three were of the teflon seated variety. Within each group of three, one valve (for control purposes) was manufactured entirely to the Rocket Research production specification, while the remaining two differed only in their "built in" seat leakage. The valves were made to leak by physically abrading the poppet sealing faces to varying degrees of surface roughness. Baseline leakage characteristics of the valves can be found in the tabulated data in Section VI of this report.

HYDRAULIC RESEARCH VALVES

The Hydraulic Research and Manufacturing Company valve was also selected by SAMSO to be tested, considering its successful use on the Intelsat satellite series. Depicted schematically in Figure 2, these valves use permanent magnet torque motors to drive their flat, lapped metal poppets. Each valve unit consists of two tungsten carbide seat/poppet sets in series to provide sealing redundancy in the normally closed off position. The general operating characteristics of the Hydraulic Research Valves are listed in Table X. They are used to control hydrazine flow to a Hamilton Standard catalytic engine, in the five pound thrust range, for satellite attitude control.

For this investigation, three Hydraulic Research valves of varying gas leakage characteristics were procured. As in the case of the Parker valves discussed earlier, one valve was built completely to the engine specification, while the remaining two differed only in internal seat leakage. Again, degradation of the poppet sealing surface finish was used to induce leakage. Baseline leakage characteristics of these valves may also be found in the tabulated data in Section VI of this report.

SECTION IV

TEST SYSTEM DESCRIPTIONS

GAS LEAKAGE SYSTEM

Measurement of nitrogen gas leakage through the valves was accomplished with a Nordquist Mark II Leak Meter manufactured by Madlab, Inc. This instrument utilizes interchangeable glass pipette flow tubes which range from one-tenth of a cubic centimeter to ten cubic centimeters full scale. The volumetric leak rate of the valve under test is measured by noting with a stop watch the time necessary for a slug of colored isopropyl alcohol to traverse a known increment of volume.

In addition to being sturdy and relatively inexpensive, the Mark II Leak Meter readily provides for horizontal positioning of the flow tubes and rapid removal of the tubes to accommodate range changes. Additionally, a vent immediately upstream of the flow tube provides a secondary escape path for the leaking fluid to prevent "blowing" the isopropyl alcohol slug out the end of the tube. Repositioning of the isopropyl alcohol slug to the zero location by physically tilting the entire apparatus allows gas leakage measurements to be repeated with a minimum amount of effort.

For consistency of test purposes, all nitrogen gas leakage measurements were made at five minute intervals after a thirty minute "stabilization" period when pressure and temperature conditions of the valve were changed. Figure 3 is a schematic representation of the system used to measure nitrogen gas leakage. Repeatability of stop watch readings was usually within ±1 percent and a ±5 percent overall leak rate error is probably a realistic figure.

LIQUID LEAKAGE SYSTEM

Demonstration of a technique(s) to easily measure liquid hydrazine leakage through the test valves was one of the primary objectives of this program. Any technique/device selected needed to be capable of measuring liquid hydrazine flow down to about 0.01 cc per hour, compatible with the hydrazine propellant, and, of course, reliable and leak free to at least 300 psig.

Earlier experimenters had used known-volume glass capillary sight tubes upstream of the leaking test valve (References 2 and 3). Positioning a hydrazine meniscus in that glass capillary tube and measuring its position change with time under known temperature and pressure conditions allowed direct calculation of the volumetric liquid flow rate over the time increment. Initial attempts to utilize this technique in this investigation resulted in the emergence of numerous difficulties. Securing a leak-free seal between the glass tubes themselves and the fittings used to incorporate those tubes into the rest of the flow system was the initial problem encountered. The fragile nature of the tubes themselves made breakage a continuous problem. Utilization of heat shrinkable polyethylene tubing around the glass tubes and a nylon sleeve around the polyethylene material to provide the seal material into which the swagelok ferrule "bites" was a successful approach to solve the external leakage problem.

Troublesome bubbles and what appeared to be vapor locks in the capillary tubes were also sources of concern. Additionally, thermal expansion and contraction effects on the columns of hydrazine visible within the tubes due to temperature changes sometimes overshadowed the meniscus position changes due to leakage. Repositioning the hydrazine meniscus was a slow process in itself, and, all factors considered, the technique was tedious and time consuming at best. Consequently, when the availability of an applicable microflowmeter (Gilmont Instruments, Inc) became known, the sight glass technique was cast aside.

The selected microflowmeter (Figure 4) is essentially a tiny rotameter calibrated for both air flow (1 to 900 scc per hour) and water flow (0.012 to 7.2 cc per hour) but in this investigation was used only to measure liquid hydrazine leakage. Viscosity and density corrections allow the user to calculate calibration curves for other fluids. Standard gas equations may be used to correct for non-standard pressure and temperature conditions. Construction being entirely of glass and teflon, with a synthetic ruby float, the flowmeter is compatible with a wide variety of corrosive fluids. The flowmeter (and the plastic safety shield) was easily adapted to the pressurized flow system with the fitting arrangement depicted in Figure 5 and was leak tight to 400 psig. A schematic of the total system used to measure liquid hydrazine leakage during this investigation depicted in Figure 6.

Besides being leak free, totally compatible with hydrazine, and individually calibrated, this type of rotameter has yet another significant advantage over the sight glass-meniscus technique. Leak rate data may be gathered at individual points in time, not as an average volumetric flow rate over some arbitrary time period. The ability to observe the dramatic variation (decrease) of liquid hydrazine leakage with time with this device made it ideal for this application. Vendor literature highlights the necessity to follow stringent cleanliness precautions when using the rotameter so as not to impede the movement of the float with residual debris. System filtration immediately upstream of the flowmeter eliminated that problem. A ±10 percent error in liquid leakage measurement as suggested by the manufacturer for rotameters in this size range is probably a realistic figure.

SECTION V

TEST RESULTS

PRESSURE EFFECTS ON LEAKAGE

When the leak rates of the respective valves were measured, whether with gas or liquid, that amount measured represented a summation of the fluid flow through each of the individual leaking "paths" present across the valve sealing area. The number and geometric configuration (length, shape, effective diameter, etc.) of these individual leak paths were unknown. Consequently, the particular mode of flow occurring within each path was also unknown. Gas flow may be either molecular, laminar, or turbulent, while liquid flow through each path could also be laminar or turbulent. It is highly probable that within a leaking valve under investigation, one would find numerous flow modes occurring in each of the neighboring leak paths and possibly even within a single leak path itself. Consequently, the measured leakage may be considered to be a "consolidation" of each of the distinct flow modes as well as their respective transition regimes. These facts alone make it a task of enormous complexity to predict the effect of valve inlet pressure on total valve seat leakage, when that fluid flow is a different function of ΔP in each flow mode.

From Reference 1, if P_1 and P_2 are downstream and upstream pressures respectively,

For Gases in the Molecular Regime, Flow is proportional to $(P_2 - P_1)$

For Gases in the Laminar Regime, Flow is proportional to $(P_2^2 - P_1^2)$

For Gases in the Turbulent Regime, Flow is proportional to $(P_2^2 - P_1^2)^{1/2}$

For liquids in the Laminar Regime, Flow is proportional to $(P_2 - P_1)$

For Liquids in the Turbulent Regime, Flow is proportional to $(P_2 - P_1)^{1/2}$

In this investigation it is unlikely that molecular flow of gases or turbulent liquid leakage occurred through any of the valves, but there is no way of being certain of that fact.

Nitrogen and hydrazine leakage measurements were made at three distinct pressure levels characteristic of the "blow-down" pressure range prevalent in the mission situation. Inlet pressures of 250, 180, and 85 psig were arbitrarily selected. For gas measurements, the valves were leaking to atmosphere (NORDQUIST leak meter on downstream side) while liquid leakage was to a downstream pressure of approximately 2 mm Hg.

The data as presented in Tables I through VIII for nitrogen and hydrazine leakage suggest two things relative to pressure dependency. Gas leakage appears to be a relatively strong function of inlet pressure, while liquid leakage appears to be a relatively weak function of inlet pressure. In some cases, liquid leakage actually continued to decrease with time as the inlet pressure was increased. To illustrate the Pressure - Time - Leakage relationship, Figures 7, 8 and 9 were prepared for both nitrogen and hydrazine leakage of each of the three selected valve designs. In each case, the maximum and minimum leakage rates measured at the respective ΔPs have been plotted for visualization. All measurements were made without valve actuation. Of particular interest is the inability to make repeat liquid leakage measurements at the given pressure levels for verification purposes, due to a time dependency. The gas leakage - versus - inlet pressure relationships, on the other hand, were as expected.

It might be noted that the rate of increase in gas leakage for the Teflon seated valves from 180 to 250 psid was lower than that increase between 85 and 180 psid. This was not the case with the hard seated valves, where the slope of the line between 180 and 250 psid was greater than between the lower pressures. A possible explanation is the fact that at the higher pressure loadings with the Teflon seat, the effective leak path diameters were significantly decreased and some may have been eliminated entirely. The liquid hydrazine leakage being more dependent on time than on pressure drop made correlation studies difficult, and will be discussed in the liquid/gas correlation section of this report.

TEMPERATURE EFFECTS ON LEAKAGE

The overall effects of increased valve temperature (to simulate thermal soakback) on seat leakage are presented in Figures 10 and 11. The data indicates a significant decrease in nitrogen leakage at each inlet pressure level when the valves' temperature was raised to 150 and 250°F. This phenomenon occurred with both the hard and teflon seated valves which were studied. Tests 1 through 64 in Table I and Tests 1 through 73 in Table II illustrate this decrease dramatically. Attempts to cause a hard seat valve to leak hydrazine by raising its temperature were unsuccessful (Table VII, Tests 29 through 35). Also, in Tests 31 and 32 of Table VIII liquid hydrazine leakage of another hard seat valve was not significantly affected by raising its temperature to 250°F. It is probable that the temperature effect on liquid hydrazine leakage is over-shadowed by the time effect which was discussed earlier.

The overall temperature effect on valve seat leakage is undoubtedly made up of its individual effects on fluid properties and leak path geometry. The lack of experimental data relative to the liquid hydrazine leakage variation with temperature prohibits speculation at this time. The effects on gas leakage demonstrated in Figures 10 and 11 warrant further discussion.

Gases are known to become more viscous at elevated temperatures, and according to Reference 5, nitrogen viscosity increases from 0.018 to 0.022 centipoise between 70°F and 250°F. Since fluid flow is inversely proportional to viscosity, this could account for part, but certainly not all of the leakage decrease at elevated temperature. It is likely that the thermal expansion effects of the elevated temperatures on the valve body and internal parts are of greater significance. Expansion and contraction of the end cap outlet (Figure 1) holding the seat as well as the spring forcing the poppet against the seat could significantly affect valve sealing properties. On a smaller scale, especially in the metal-to-metal seat configurations, the leak path diameters could be affected by the elevated temperatures. As depicted in Figures 10 and 11, as the valve was cooled down, the leakage rates returned nearly completely to their initial values. A slight change in the leakage characteristics of the teflon seated valve was noted, but this should be expected, due to the swaged nature of that seat configuration that is unrestrained on one side.

CYCLING EFFECT ON LEAKAGE

The effect of valve actuation in a hydrazine environment on valve seat leakage is illustrated in Figures 12 and 13 for both the hard and teflon seat designs respectively. The Parker hard seat valve S/N 103 was actuated 10,000 times at a frequency of 1 Hz in hydrazine at a 10 psi pressure drop to conserve propellant. A definite decrease in nitrogen leakage characteristics tabulated in Table I, (Tests 89 through 108 and 159 through 178) was noted. Similarly, the Parker Teflon seat valve S/N 10[illegible] was actuated a total of 12,000 times with an even more significant decrease in nitrogen leakage noted (Table II, Tests 58 through 75 and 80 through 94).

Whereas opening and closing a valve usually resulted in random variation of leakage characteristics, extended cycling in a relatively particulate-free environment affects the poppet/seat interface roughness to a much greater degree. Peaks and valleys causing leakage may be thought to be pounded down with the repeated impact condition. With the resultant "improvement" in surface roughness characteristics in sealing areas, the internal leakage might be expected to decrease. The leakage data generated in this program seems to substantiate that hypothesis.

CORRELATION OF LIQUID AND GAS LEAKAGE

The primary objective of this investigation was to establish a meaningful correlation between nitrogen gas and hydrazine liquid leakage at pressures ranging from 85 to 250 psid. A band of correlation data was expected, since gas and liquid flows increase at different rates with pressure. As explained by Marr (Reference 1) the most familiar flow equation for the laminar flow of gases through a straight tube of circular cross-section was developed by Poiseuille (Reference 5).

$$Q = \frac{\pi}{8}\left(\frac{d}{2}\right)^4 \frac{P_a}{\mu \ell}\left(P_2 - P_1\right)$$

where

Q = mass flow of gas in units of atm cc/time

d = diameter of flow path

P_a = average pressure across the flow path $\frac{P_2 - P_1}{2}$

μ = absolute viscosity of the gas

ℓ = length of the flow path

P_2 = inlet pressure

P_1 = outlet pressure

Similarly, for the non-turbulent flow of a liquid through the same tube,

$$Q = \frac{\pi}{8}\left(\frac{d}{2}\right)^4 \frac{1}{\mu \ell}\left(P_2 - P_1\right)$$

Although we recognize that the flow phenomenon under consideration here is not through single, uniform diameter, uniform length, circular leak paths, the equations may still be used to predict the liquid/gas relationship as explained below.

The terms $\left(\frac{\pi}{8}\right)\left(\frac{d}{2}\right)^4\left(\frac{1}{\ell}\right)$ appear in both equations. Therefore, unless the valve is actuated, all leakage should be through the same paths when changing from gas to liquid so the common terms reduce to a common geometric constant and the overall relationships reduce to:

$$Q = K_{geom}\, Pa \frac{1}{\mu}\left(P_2 - P_1\right) \quad \text{for } \underline{\text{gases}}$$

and

$$Q = K_{geom} \frac{1}{\mu}\left(P_2 - P_1\right) \quad \text{for } \underline{\text{liquids}}$$

so, although we do not know the exact values of ℓ, d, etc, we assume they will be the same for both gas and liquid flow since the valve is not actuated. By measurement of gas leakage, and knowing the pressure conditions, K_{geom} may be calculated and used in the second equation to predict the liquid flow. The theoretical correlation band between 85 and 250 psid shown on Figure 14 was constructed using this technique. Santler and Moller (Reference 4) have used these equations to construct a nomograph which is widely used for prediction purposes.

A major problem was encountered when approaching the gas leak and liquid leak data presented in Tables I through VIII from the correlation standpoint. As Figures 7, 8, and 9 illustrate, a wide range of liquid leak rates are found to correspond to the gas leakage measured at a particular pressure level. As discussed previously, the liquid leak rate usually decreased with time (Table I, tests 136 through 141). For consistency, and to maintain the highest degree of conservatism possible, the largest hydrazine leakage rates were paired with their corresponding minimum nitrogen leakage in the correlation data summary in Table XI. These data are plotted on Figure 14 along with the theoretical correlation band.

To note the effect of particulate contamination on the liquid/gas correlation (essentially inducing a change in the leak path geometry) selected valves were contaminated with 3-20 micron tungsten and aluminum powder (see Tables I and III). Those data are also summarized in Table XI and identified on Figure 14. It should be noted that the tendencies for liquid leakage to decrease with time were more pronounced in those cases where the valves had been artificially contaminated with the tiny particles. It is conceivable that although the trapped particles allowed much more nitrogen to leak (many relatively small leak paths) the smaller path sizes did not allow the liquid to leak through. Particle movement into and through the leak paths may have caused decreases in effective diameter and perhaps clogging of some of the paths entirely.

Thorough explanations of any or all of the data presented here is only speculative at best, and cannot be fully substantiated in this investigation. The limited number of valves used and the statistically small amount of data collected should temper any conclusions drawn by the reader.

SECTION VI

CONCLUSIONS

A number of overall conclusions can be drawn from analysis of the leakage test data generated during this program. These conclusions are:

1. While nitrogen gas leakage is a strong function of valve inlet pressure, liquid hydrazine leakage is a very weak function of inlet pressure.

2. Liquid hydrazine leakage exhibits definite tendencies to decrease with valve exposure time to propellant.

3. Temperature studies to 250°F demonstrated an inverse relationship between valve temperature and nitrogen leak rate.

4. Cycling studies demonstrated a random leakage variation with each valve actuation, but a definite decrease in nitrogen leakage with extended cycling in the hydrazine propellant.

5. Attempts to establish a well-defined correlation between hydrazine and nitrogen leakage were hindered by the significant liquid leakage variation with time.

In addition, the demonstrated ease of use of a small, commercially available rotameter indicates its excellent applicability to the measurement of small hydrazine leakage rates.

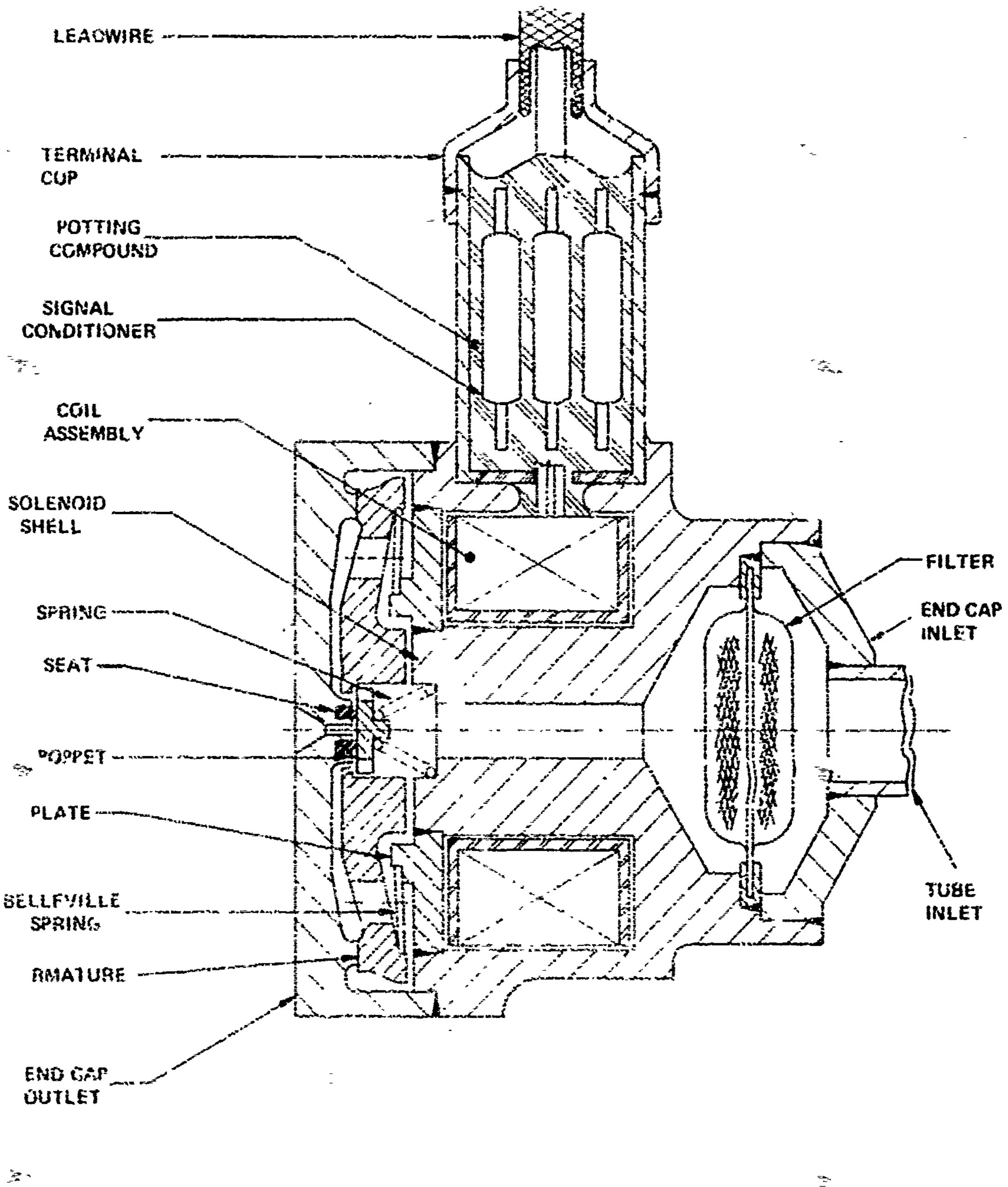

Figure 1. Parker Hannifin Valve (Teflon Seat)

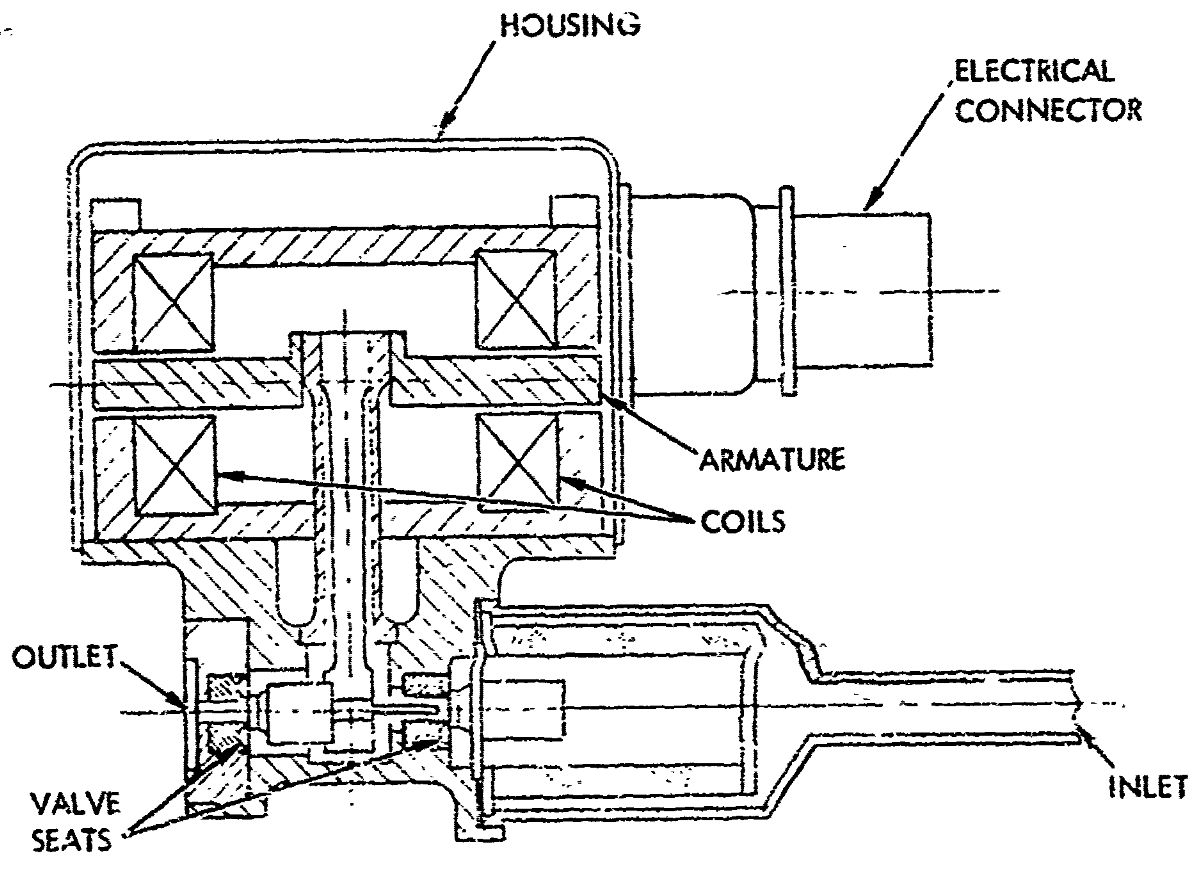

Figure 2. Hydraulic Research and Manufacturing Company Valve

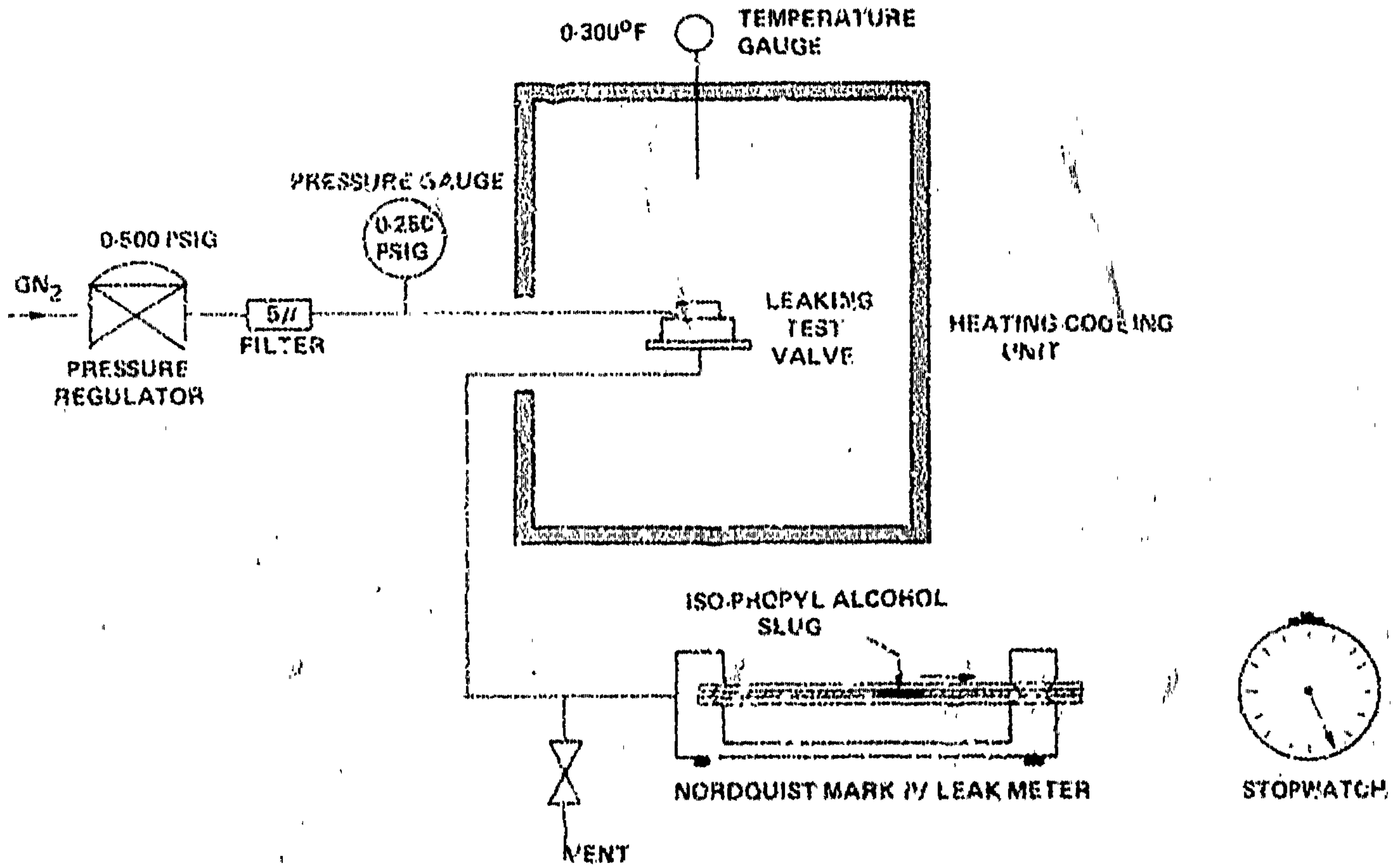

Figure 3. Nitrogen Leak Measurement System

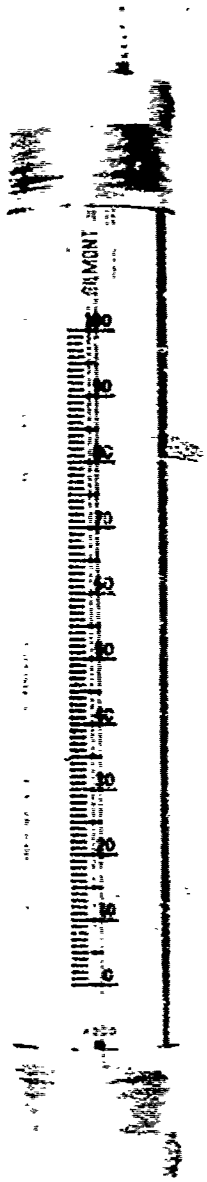

Figure 4. Gilmont Microflowmeter

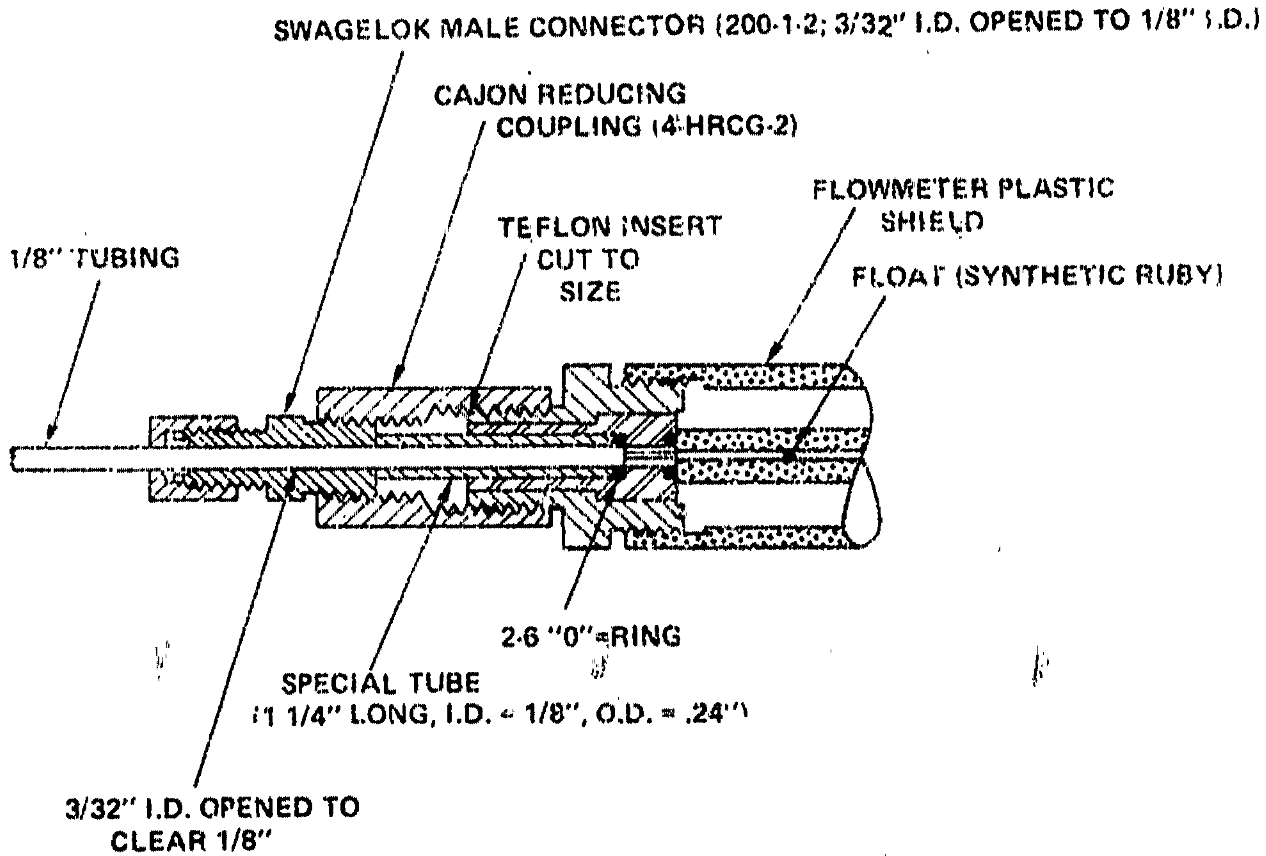

Figure 5. Gilmont Microflowmeter High Pressure Fitting Arrangement

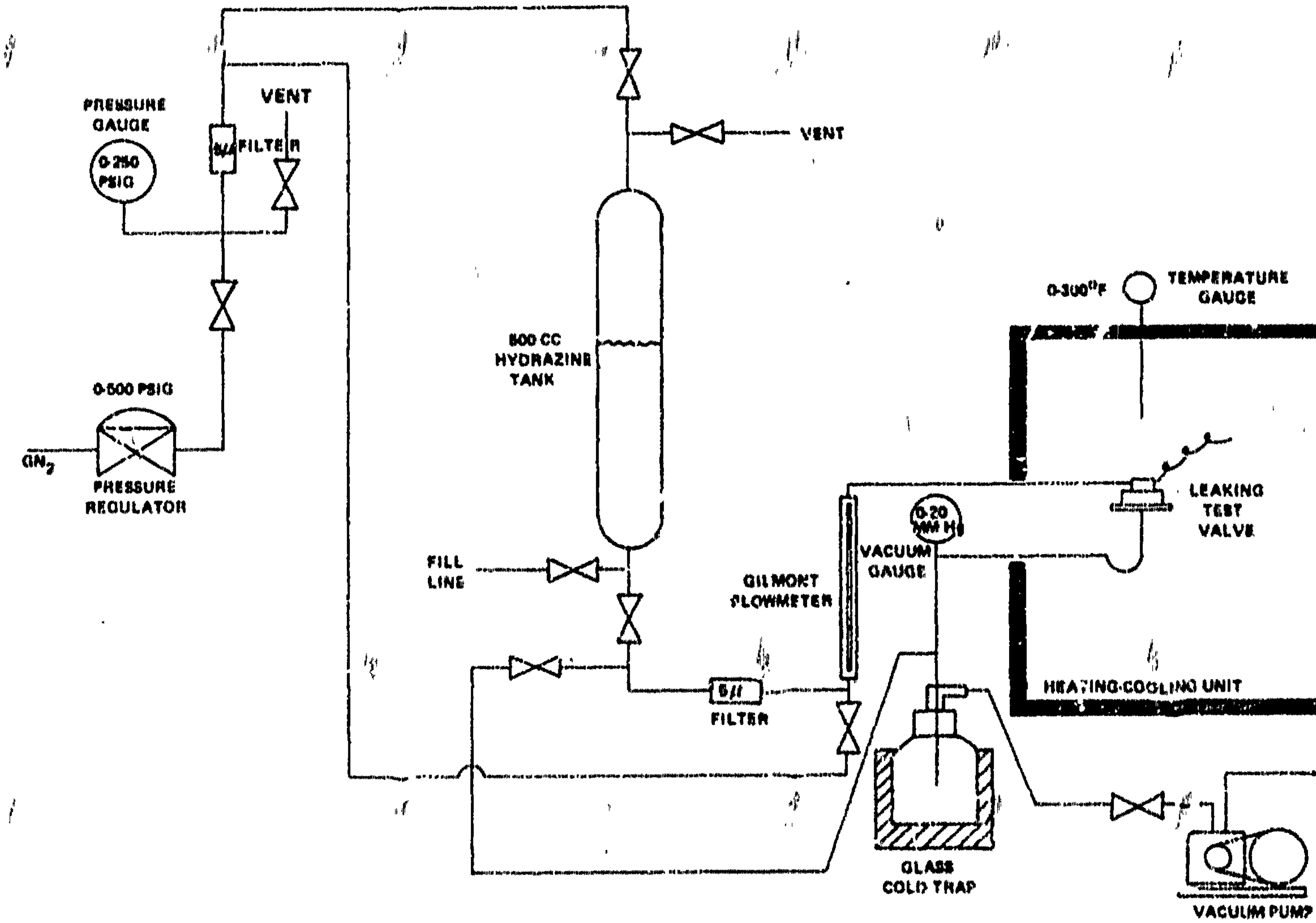

Figure 6. Hydrazine Leak Measurement System

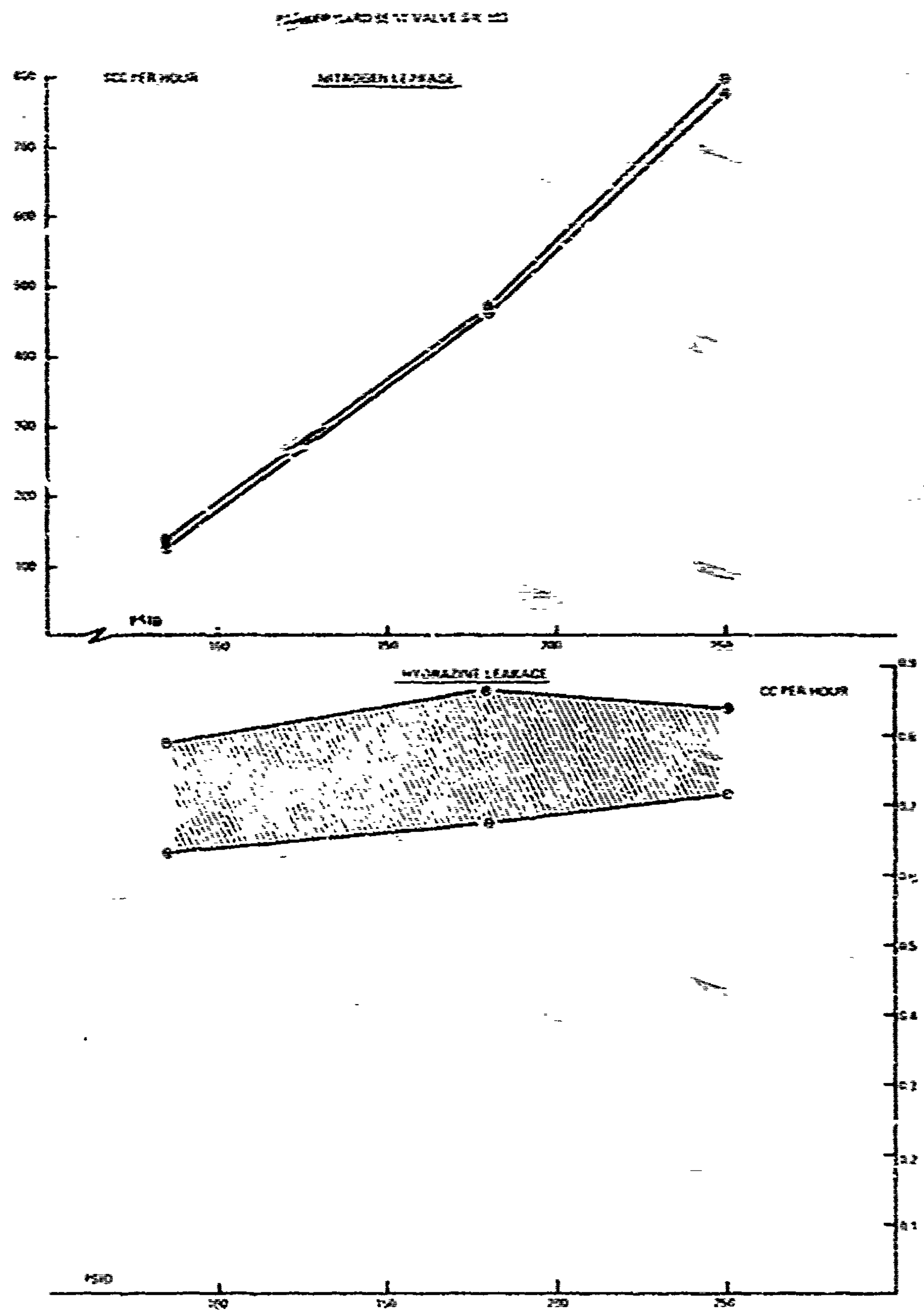

Figure 7. Leakage versus Pressure

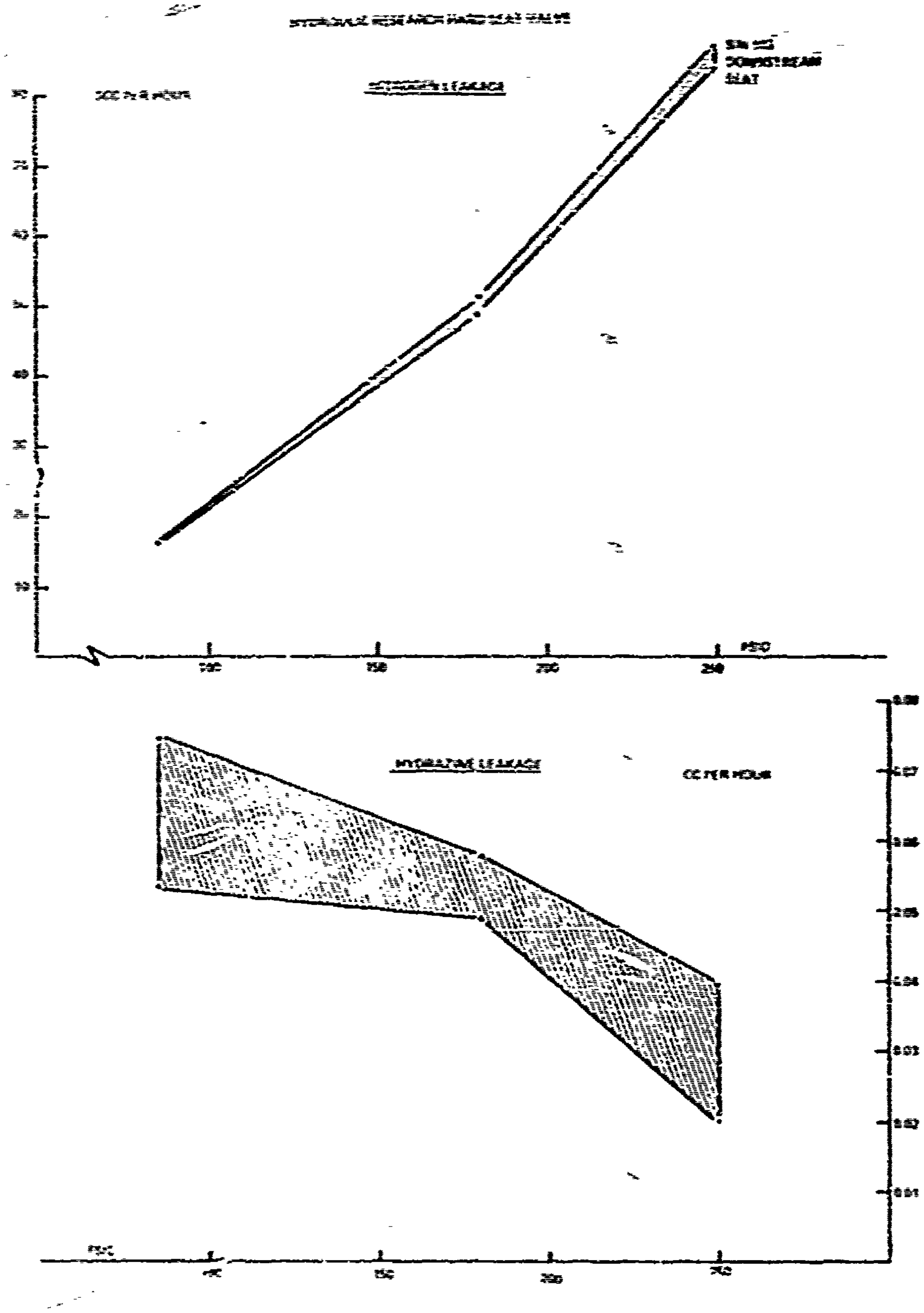

Figure 8. Leakage versus Pressure

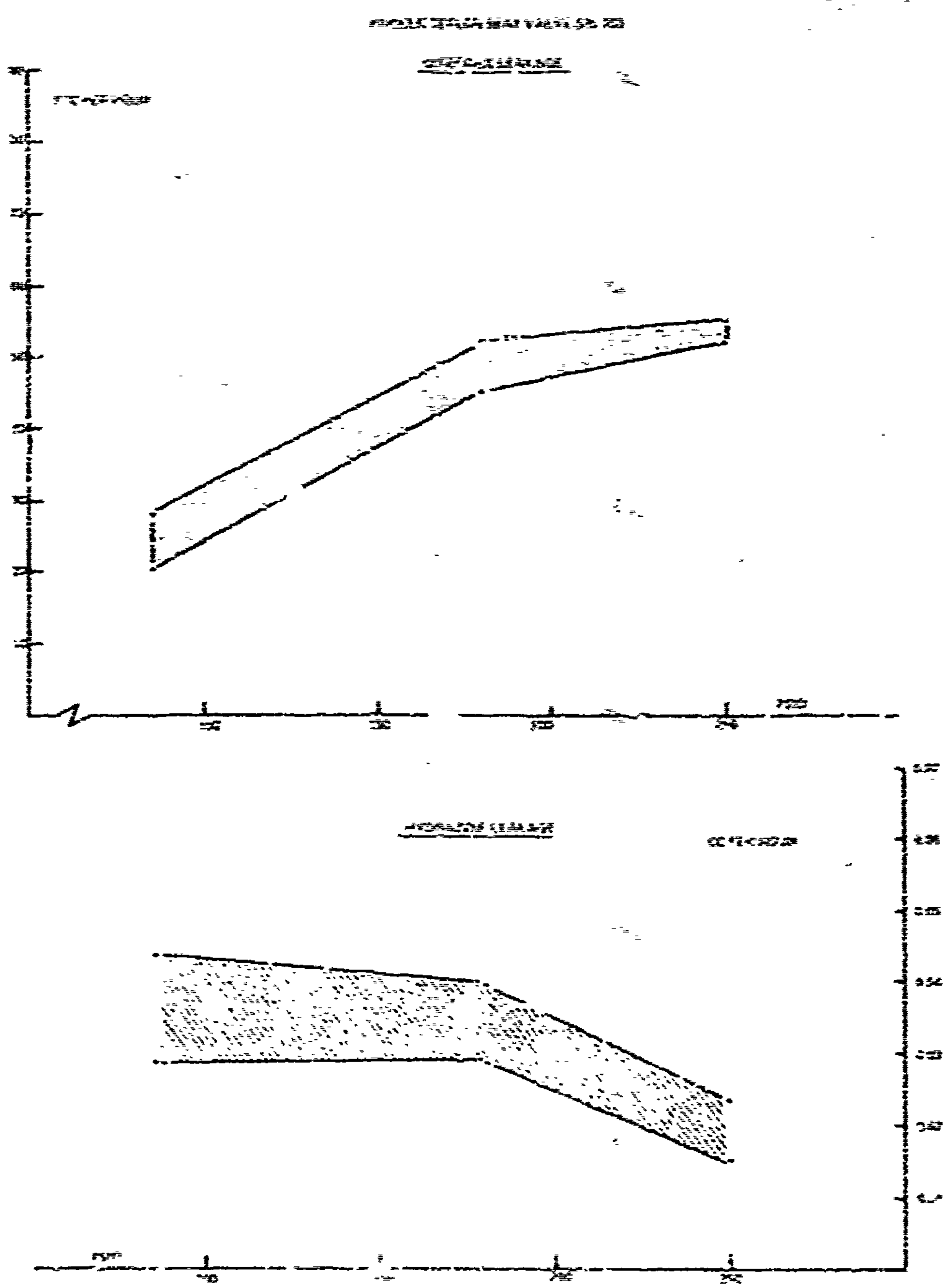

Figure 9. Leakage versus Pressure

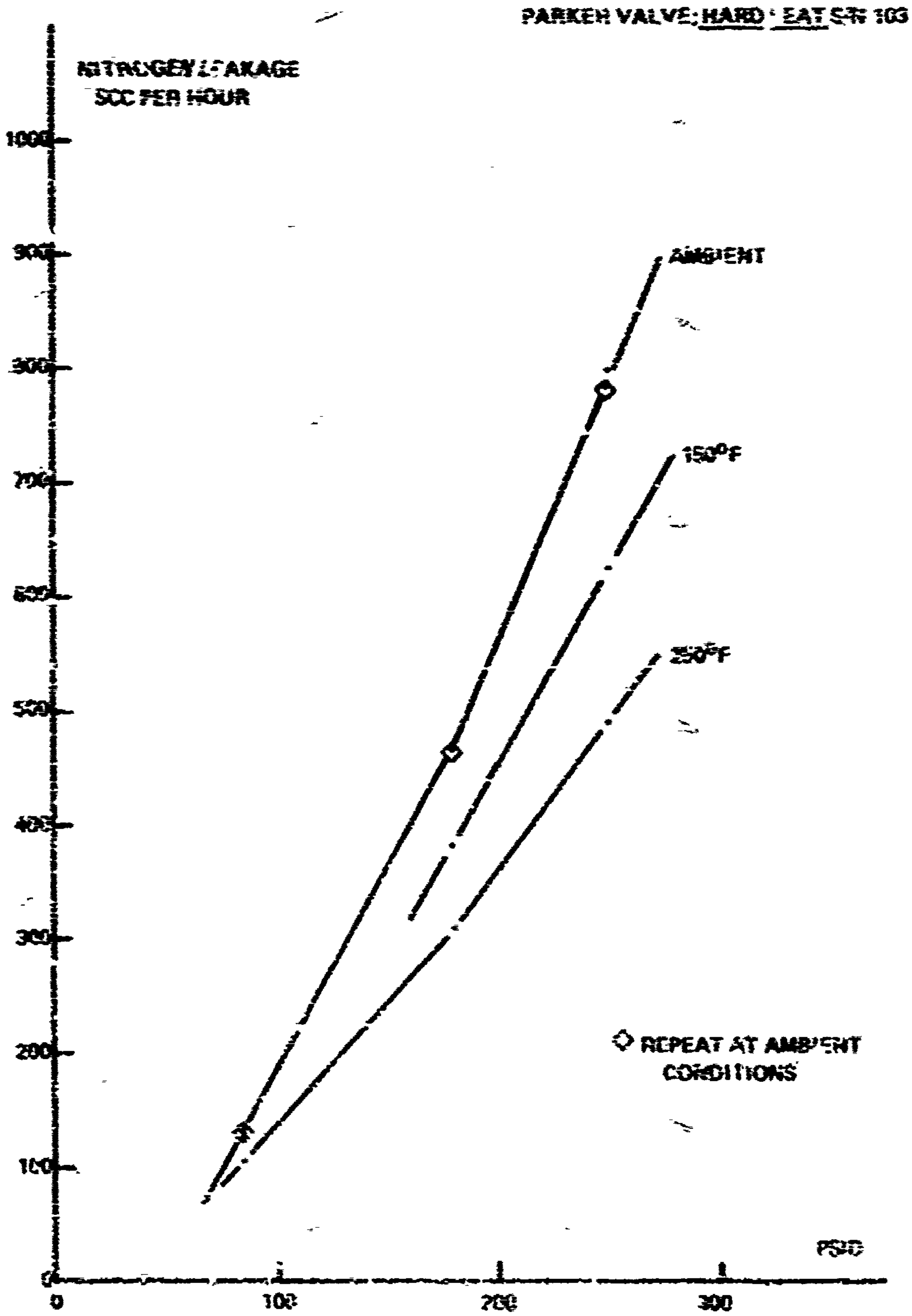

Figure 10. Temperature Effect on Leakage

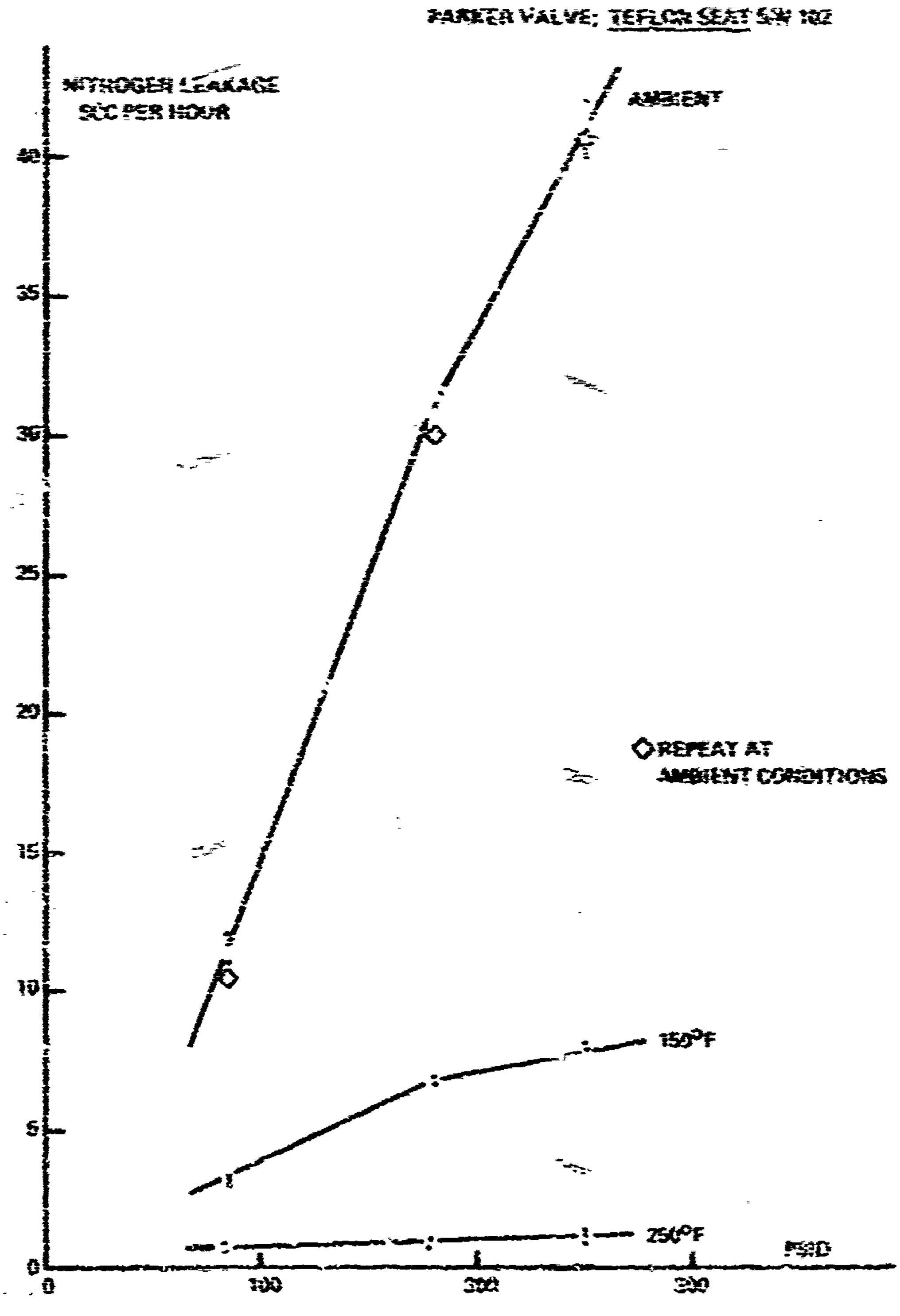

Figure 11. Temperature Effect on Leakage

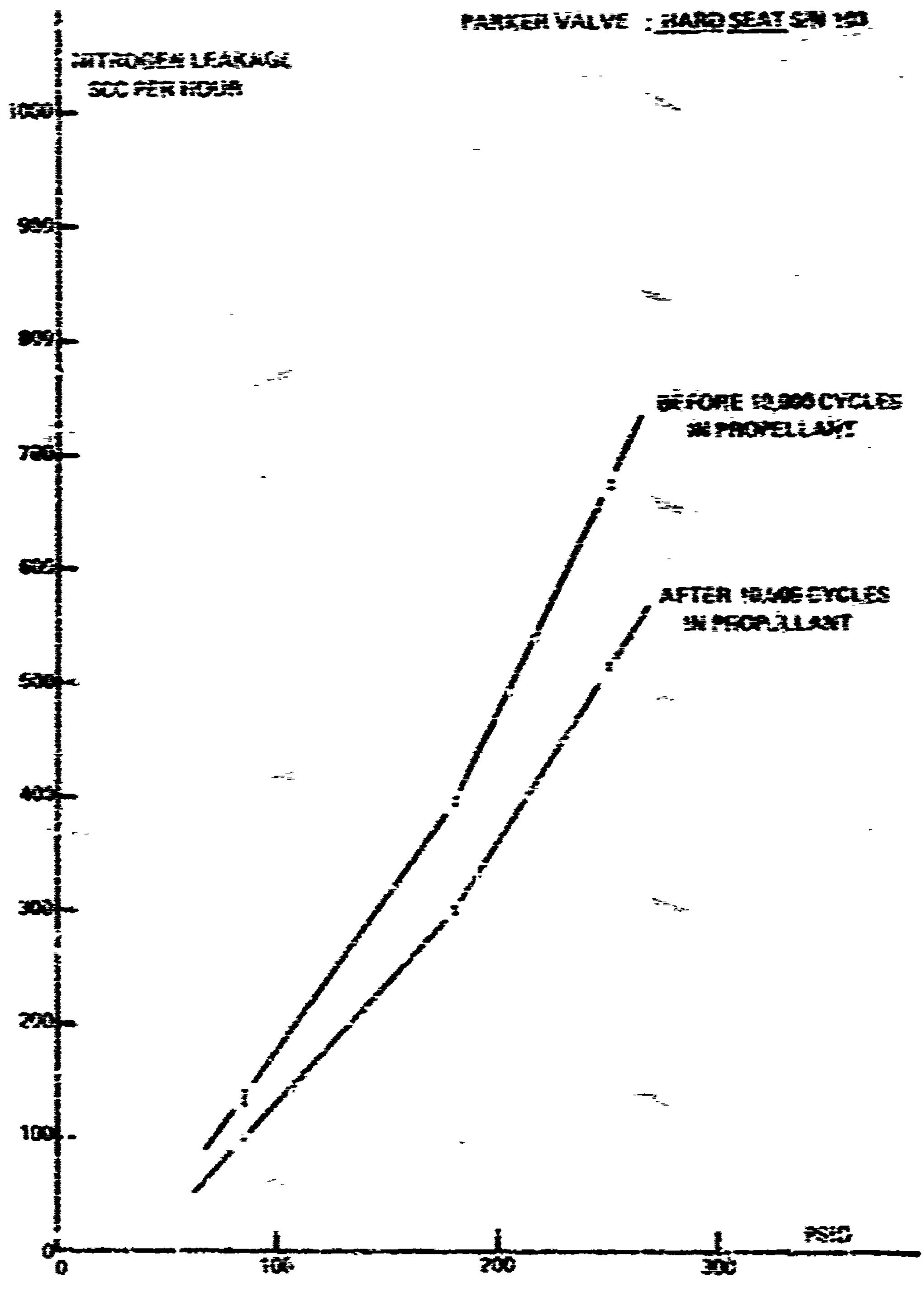

Figure 12. Cycling Effect on Leakage

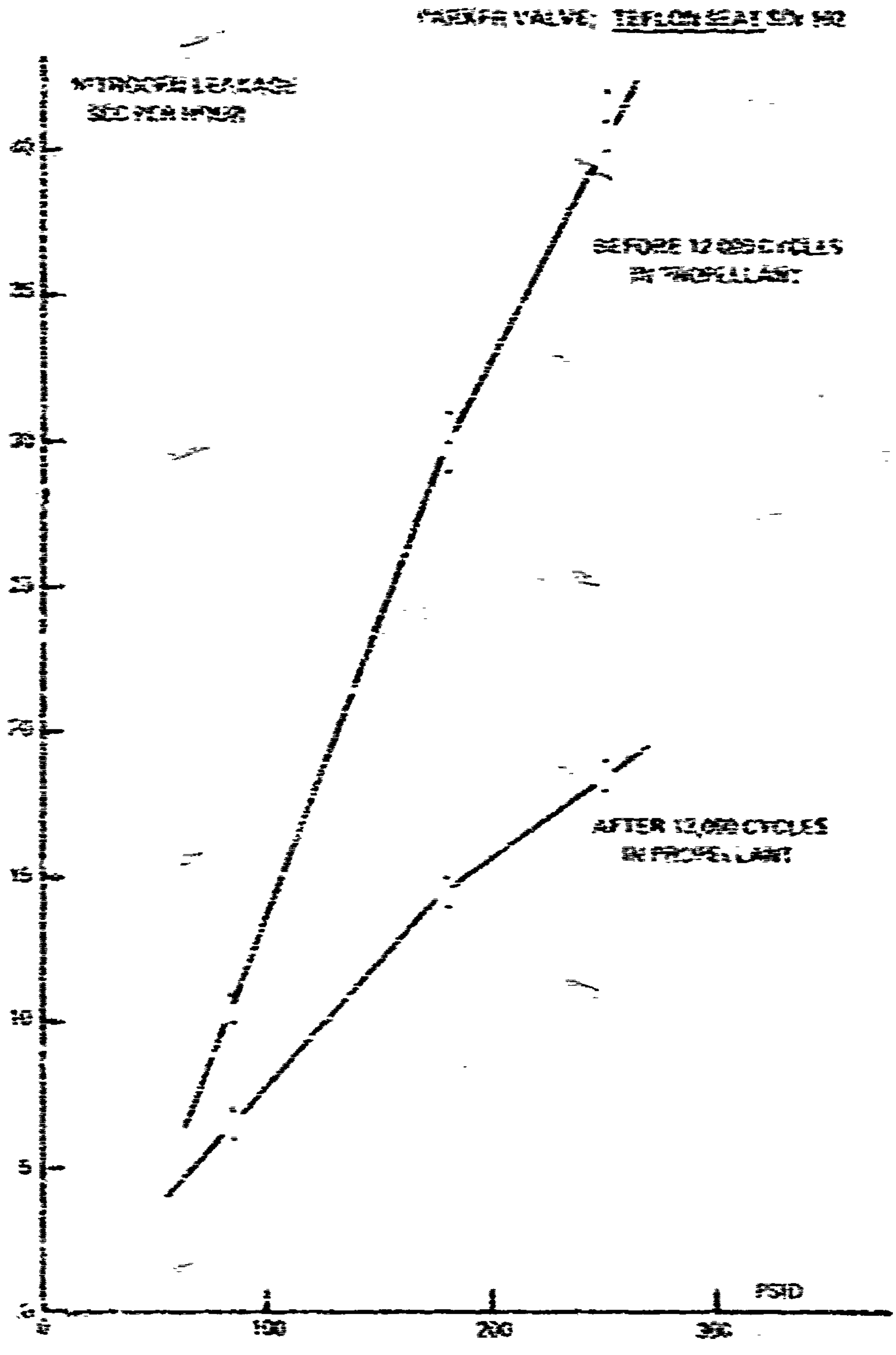

Figure 13. Cycling Effect on Leakage

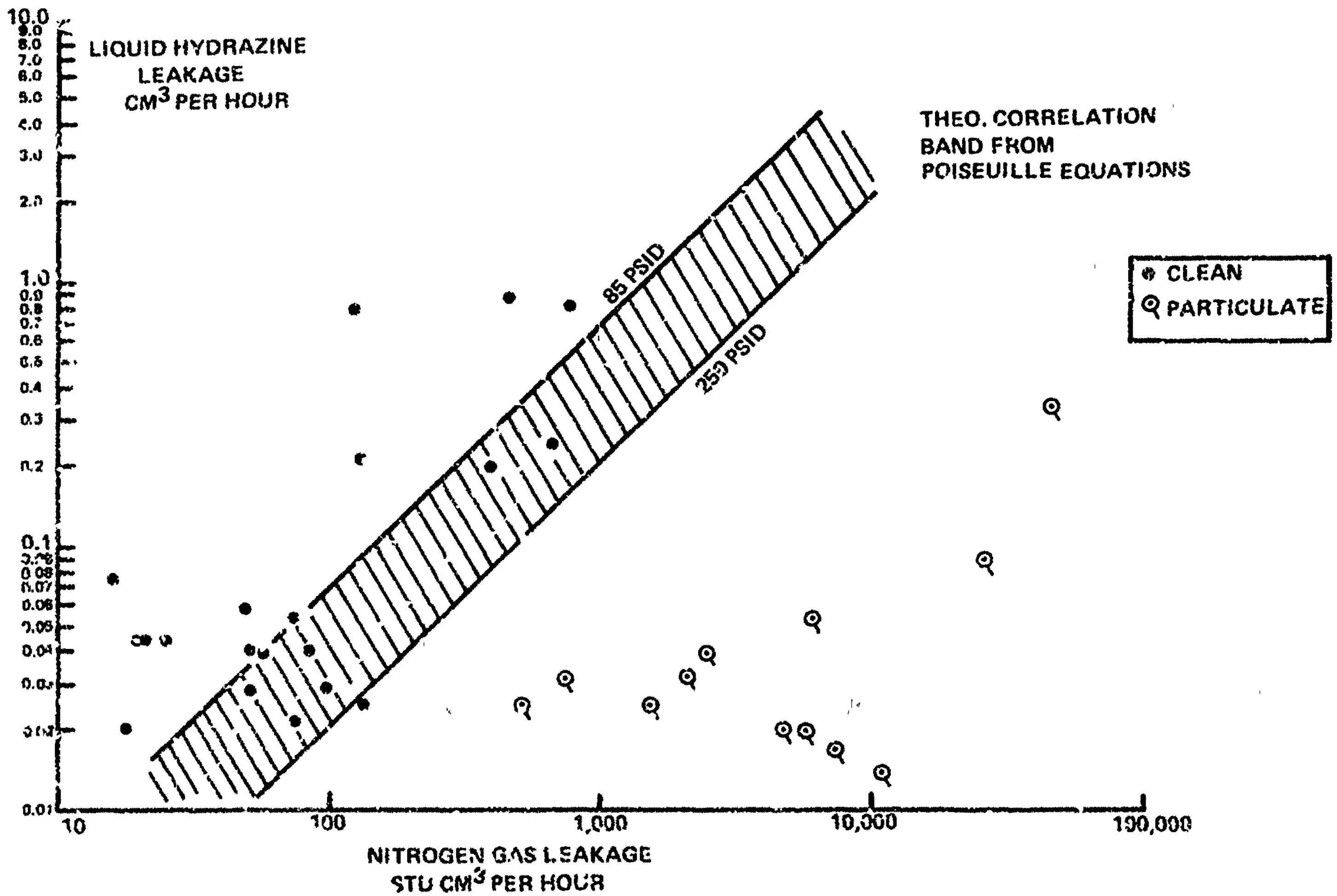

Figure 14. Liquid versus Gas Leakage.

TABLE I. LEAKAGE DATA

TEST ITEM: PARKER VALVE/HARD SEAT, 103

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	131 scc/hr	
2				125	
3				138	
4				137	
5				138	
6				136	
7				135	
8				135	
9				136	
10				135	
11				128	
12				136	
13				136	
14				136	
15				136	
16			180 psig	469	
17				472	
18				470	
19				471	
20				471	
21			250 psig	800	
22				786	
23				786	
24				786	
25		150°F		627	
26				627	
27				625	
28				625	
29				625	
30			180 psig	385	
31				385	
32				384	
33				383	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
34	Nitrogen	150°F	180 psig	384 scc per hour	
35		250°F	250 psig	492	
36				492	
37				492	
38				491	
39				491	
40			180 psig	309	
41				308	
42				308	
43				307	
44				308	
45			85 psig	107	
46				105	
47				105	
48				105	
49				105	
50		Ambient		134	
51				135	
52				134	
53				136	
54				137	
55			180 psig	466	
56				466	
57				462	
58				469	
59				471	
60			250 psig	720	
61				779	
62				781	
63				786	
64				785	
65	Hydrazine	Ambient	85 psig	.788 cc per hour	Begin N_2H_4 Tests
66	Hydrazine	Ambient	85 psig	.740	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
67	Hydrazine	Ambient	85 psig	.717 cc per hour	
68				.650	
69				.628	
70			189 psig	.672	
71				.672	
72				.788	
73				.863	
74				.863	
75			250 psig	.835	
76				.788	
77				788	
78				.788	
79				.764	
80				.764	
81				.740	
82				740	
83				.717	Isolated in N_2H_4 @ 85 psig for 16 hrs
84			250 psig	[illegible]	
85				.0?4	
86				.094	
87				.094	
88				.081	Vacuum Baked 15 hrs
89	Nitrogen	Ambient	85 psig	140 scc per hour	
90				133	
91				[illegible]	
92				[illegible]	
93				[illegible]	
94				144	
95				[illegible]	
96				130	
97				134	
98				134	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
99	Nitrogen	Ambient	180 psig	400 scc per hour	
100				399	
101				400	
102				397	
103				396	
104			250 psig	674	
105				674	
106				674	
107				679	
108				672	Repeat N_2H_4 Tests
109	Hydrazine	Ambient	85 psig	.211 cc per hr	
110				.200	
111				.179	
112			180 psig	.200	
113				.200	
114				.200	
115			250 psig	.211	
116				.200	
117				.179	Isolated in N_2H_4 @ 85 psig for 64 hrs
118	Hydrazine	Ambient	250 psig	.246	
119				.141	
120				.081	
121				.064	
122				.058	Isolated in N_2H_4 @ 85 psig for 18 hrs
123	Hydrazine	Ambient	85 psig	[illegible]	
124				.036	
125			180 psig	.063	
126				.058	
127			250 psig	.075	
128				.069	
129				.049	Cycle 10,000 times in Propellant

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
130	Hydrazine	Ambient	85 psig	.189 cc per hour	
131				.150	
132				.124	
133			180 psig	.141	
134				.124	
135				.094	
136			250 psig	.088	
137				.081	
138				.069	
139				.058	
140				.049	
141				.044	Isolated in N_2H_4 @ 85 psig for 16 hrs
142			250 psig	.069	
143				.058	
144				.053	
145				.053	
146			180 psig	.049	
147				.036	
148				.029	
149			85 psig	.058	
150				.053	
151				.049	
152				.044	
153				.040	
154			250 psig	.075	
155				.069	
156				.054	
157				.053	
158				.053	Vacuum Bake 18 hrs
159	Nitrogen	Ambient	85 psig	100 sec per hr	
160				100	
161				100	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ± 2 psig	Leakage cc per hr	Remarks
162	Nitrogen	Ambient	85 psig	99 scc per hr	
163				99	
164				100	
165				100	
166				100	
167				100	
168				99	
169			180 psig	302	
170				302	
171				302	
172				300	
173				302	
174			250 psig	517	
175				517	
176				514	
177				517	
178				514	Into Ambient Storage
179	Nitrogen	Ambient	85 psig	103	
180				105	
181				101	
182			180 psig	277	
183				277	
184				277	
185			250 psig	424	
186				419	
187				424	Contaminated with Tungsten particles
188	Nitrogen	Ambient	85 psig	541	
189				534	
190				522	
191			180 psig	1525	
192				1525	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
193	Nitrogen	Ambient	180 psig	1525 scc per hr	
194			250 psig	2504	
195				2549	
196				2549	Begin N_2H_4 Tests
197	Hydrazine	Ambient	85 psig	.025 cc per hr	
198				.020	
199				.015	
200			180 psig	.025	
201				.020	
202			250 psig	.040	
203				.036	
204				.029	
205				.025	
206				.025	
207				.022	
208				.020	
209				.015	
210				.015	
211				.012	
212				.010	Isolated in N_2H_4 @ 85 psig for 38 hrs
213	Hydrazine	Ambient	250 psig	Not Measurable	Vacuum Baked 30 hrs
214	Nitrogen	Ambient	55 psig	2118 scc per hr	
215				2118	
216				2093	
217			160 psig	4500	
218				4390	
219				4390	
220			185 psig	4737	
221				4737	
222				4865	
223	Nitrogen	Ambient	250 psig	6000 scc per hour	
224				6000	
225				6207	

TABLE I. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
226	Hydrazine	Ambient	85 psig	.032 cc per hour	
227				.029	
228				.025	
229				.022	
230				.020	
231				.015	
232			180 psig	.020	
233				.015	
234			250 psig	.053	
235				.049	
236				.044	
237				.040	
238				.036	
239				.036	
240				.032	
241				.029	
242				.022	
243				.022	
244				.020	
245				.020	
246				.020	Vacuum Bake 18 hrs
247	Nitrogen	Ambient	85 psig	2466 scc per hr	
248				2432	
249				2466	
250			180 psig	6667	
251				6429	
252				6429	
253			250 psig	10,000	
254				10,588	
255				10,000	Final Test

TABLE II. LEAKAGE DATA

TEST ITEM: PARKER VALVE/TEFLON SEAT, 102

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	12 scc per hour	
2				12	
3				12	
4				12	
5				12	
6				12	
7				11	
8				11	
9				12	
10				12	
11				12	
12				11	
13				11	
14				12	
15				12	
16				12	
17				12	
18				12	
19				12	
20			150 psig	31	
21				31	
22				31	
23				31	
24				31	
25				31	
26				31	
27				31	
28			250 psig	42	
29				42	
30				40	
31				40	
32		150°F		7.8	
33				7.9	

TABLE II. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
34	Nitrogen	150°F	250 psig	7.7 scc per hour	
35				7.7	
36				7.7	
37			180 psig	6.7	
38				6.7	
39				6.7	
40				6.7	
41				6.6	
42			85 psig	3.3	
43				3.2	
44				3.2	
45				3.3	
46				3.3	
47		250°F	250 psig	1.[illegible]	
48				1.1	
49				0.9	
50			160 psig	1.1	
51				1.0	
52				0.9	
53				0.8	
54			85 psig	0.8	
55				0.7	
56				0.8	
57				0.8	
58	Nitrogen	Ambient	85 psig	10	
59				11	
60				[illegible]	
61				10	
62				10	
63			180 psig	31	
64				30	
65				29	
66				29	

TABLE II. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
67	Nitrogen	Ambient	180 psig	30 scc per hour	
68				31	
69			250 psig	[illegible]	
70				40	
71				41	
72				[illegible]	
73				42	
74	Hydrazine	Ambient	85 psig	Not Measurable	Begin N_2H_4 Tests
75			180 psig	Not Measurable	
76			250 psig	Not Measurable	Cycle 12,000 times in Propellant
77	Hydrazine	Ambient	85 psig	Not Measurable	
78			180 psig	Not Measurable	
79			250 psig	Not Measurable	Vacuum Bake 16 hrs
80	Nitrogen	Ambient	85 psig	7	
81				7	
82				6	
83				5	
84				5	
85			180 psig	15	
86				15	
87				15	
88				[illegible]	
89				15	
90			250 psig	18	
91				[illegible]	
92				[illegible]	
93				[illegible]	
94				[illegible]	Final Test

TABLE III. LEAKAGE DATA

TEST ITEM: PARKER VALVE/HARD SEAT, 102

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	25 scc per hr	
2				25	
3				25	
4			180 psig	52	
5				52	
6				52	
7			250 psig	74	
8				74	
9				74	
10				74	
11			180 psig	53	
12				53	
13				52	
14				51	
15				52	
16			85 psig	26	
17				26	
18				26	
19				25	
20				26	
21	Hydrazine	Ambient	85 psig	.044 cc per hr	Begin N_2H_4 Tests
22				.040	
23				.036	
24				.036	
25				.032	
26				.029	
27				.025	
28			180 psig	.040	
29				.036	
30				.032	
31				.029	
32				.029	
33				.025	

TABLE III. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
34	Hydrazine	Ambient	250 psig	.033 cc per hr	
35				.044	
36				.040	
37				.040	
38				.036	
39				.032	
40				.032	
41				.032	
42				.032	
43				.032	
44				.032	
45				.032	Vacuum Bake 18 hrs
46	Nitrogen	Ambient	95 psig	22 scc per hr	
47				24	
48				25	
49				22	
50				22	
51			150 psig	[illegible]	
52				49	
53				45	
54				50	
55				52	
56			250 psig	70	
57				67	
58				69	
59				71	
60				73	
61			150 psig	48	
62				48	
63				50	
64				49	
65				48	

TABLE III. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
66	Nitrogen	Ambient	85 psig	22 scc per hr	
67				22	
68				22	
69				23	
70				24	Contaminated with aluminum
71	Nitrogen	Ambient	85 psig	.5	
72				9	
73				769	
74			180 psig	5737	
75				5757	
76				5772	
77			250 psig	12,536	
78				12,562	
79				12,562	
80				11,240	
81				11,219	
82				11,398	
83			180 psig	5742	
84				5680	
85			85 psig	1207	
86				1135	
88				1168	
89	Hydrazine	Ambient	85 psig	.032 cc per hr	Begin N_2H_4 Tests
90				.025	
91				.020	
92				.015	
93			180 psig	.020	
94				.017	
95				.017	
96				.015	

TABLE III. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
97	Hydrazine	Ambient	180 psig	.012 cc per hr	
98			250 psig	.012	
99				.014	
100				.012	
101				.010	
102				.010	Isolated in N_2H_4 @35 psig for 23 hrs
103			85 psig	Not measurable	
104			180 psig	Not measurable	
105			250 psig	Not measurable	Valve actuated once
106			250 psig	.029	
107				.029	
108				029	
109				.025	
110				.025	
111				.022	
112				020	
113				017	
114				.012	Isolated in N_2H_4 @ 250 psig for 20 hrs
115			250 psig	Not measurable	Vacuum Bake 18 hrs
116	Nitrogen	Ambient	85 psig	7600 scc per hr	
117				7460	
118				7560	
119			180 psig	26,000	
120				26,000	
121				26,000	
122			250 psig	45,000	
123				45,000	
124				45,000	

TABLE III. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
125	Hydrazine	Ambient	250 psig	.340 cc per hr	Begin N_2H_4 tests
126				.340	
127				.298	
128				.284	
129				.258	
130				.234	
131				.200	
132				.200	
133				.195	
134			180 psig	.088	
135				.088	
136				.081	
137				.081	
138				.075	
139				.075	
140				.075	
141				.075	
142				.075	
143			85 psig	.017	
144				.017	
145				.015	
146				.012	Isolated in N_2H_4 @85 psig for 16 hrs
147			85 psig	.017	
148			180 psig	.069	
149				.069	
150				.064	
151				.064	
152				.058	
153				.053	
154			250 psig	.081	
155				.075	
156				.075	

TABLE III. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
157	Hydrazine	Ambient	250 psig	.075 cc per hour	
158				.069	
159				.064	Vacuum Bake 18 hrs
160	Nitrogen	Ambient	85 psig	804 scc per hour	
161				804	
162				811	
163			180 psig	2169	
164				2169	
165				2169	
166			250 psig	3461	
167				3273	
168				3529	
169			180 psig	2100	
170				2096	
171				2100	
172			85 psig	796	
173				804	
174				804	Final Test

TABLE IV. LEAKAGE DATA

TEST ITEM: PARKER VALVE/TEFLON SEAT, 103

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	26 scc per hour	
2				27	
3				28	
4				28	
5				27	
6				28	
7				28	
8				28	
9				28	
10				28	
11			180 psig	52	
12				52	
13				52	
14				52	
15				52	
16			250 psig	54	
17				55	
18				54	
19				55	
20				55	
21			180 psig	52	
22				51	
23				52	
24				51	
25				51	
26			85 psig	25	
27				25	
28				26	
29				26	
30				26	
31			180 psig	45	
32				46	
33				45	

TABLE IV. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
34	Nitrogen	Ambient	250 psig	53 scc per hour	
35				52	
36				52	
37				52	
38				52	
39				52	
40				52	
41				52	
42				51	
43			65 psig	21	
44				20	
45				21	
46				21	
47	Hydrazine	Ambient	65 psig	.044 cc per hour	Begin N_2H_4 Tests
48				.040	
49				.040	
50				.036	
51				.032	
52				.029	
53			180 psig	.029	
54				.040	
55				.040	
56				.036	
57				.040	
58				.029	
59			250 psig	.029	
60				.025	
61				.017	
62				.015	
63				.015	Vacuum Bake 18 hrs
64	Nitrogen	Ambient	65 psig	21 scc per hour	
65				20	
66				20	

TABLE IV. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
67	Nitrogen	Ambient	85 psig	20 scc per hour	
68				21	
69			180 psig	43	
70				42	
71				40	
72				41	
73				41	
74			250 psig	50	
75				51	
76				53	
77				50	
78				50	Final Test

TABLE V. LEAKAGE DATA

TEST ITEM: HYDRAULIC RESEARCH VALVE/UPSTREAM SEAT, 102

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	4.1 scc per hour	
2				4.0	
3				4.1	
4				4.1	
5				4.1	
6			180 psig	11.0	
7				10.9	
8				11.0	
9				10.9	
10				11.0	
11			250 psig	17.5	
12				17.9	
13				18.0	
14				18.1	
15				18.0	
16	Hydrazine	Ambient	85 psig	Not Measurable	Begin N_2H_4 Tests
17			180 psig	Not Measurable	
18			250 psig	Not Measurable	Valve Actuated Once
19			85 psig	Not Measurable	
20			180 psig	Not Measurable	
21			250 psig	Not Measurable	Valve Actuated 10 times
22			85 psig	Not Measurable	
23			180 psig	Not Measurable	
24			250 psig	Not Measurable	
25		250°F	85 psig	Not Measurable	
26			180 psig	Not Measurable	
27			250 psig	Not Measurable	Vacuum Bake 18 hrs

TABLE V. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
28	Nitrogen	Ambient	85 psig	7.1 scc per hr	
29				7.1	
30				7.0	
31				7.0	
32				7.0	
33			150 psig	18.0	
34				16.6	
35				18.9	
36				17.5	
37				18.1	
38			250 psig	28.6	
39				29.1	
40				28.6	
41				28.6	
42				28.2	Final Test

TABLE VI. LEAKAGE DATA

TEST ITEM: HYDRAULIC RESEARCH VALVE/ DOWNSTREAM SEAT, 102

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	2.6 scc per hour	
2				2.6	
3				2.6	
4				2.6	
5				2.6	
6			150 psig	7.1	
7				7.1	
8				7.3	
9				7.9	
10				7.4	
11			250 psig	11.7	
12				11.8	
13				11.7	
14				11.9	
15				11.5	
16	Hydrazine	Ambient	85 psig	Not Measurable	Begin N_2H_2 Tests
17			150 psig	Not Measurable	
18			250 psig	Not Measurable	Valve Actuated Once
19			85 psig	Not Measurable	
20			150 psig	Not Measurable	
21			250 psig	Not Measurable	Valve Actuated 100 times Vacuum Bake 18 hrs
22	Hydrazine		85 psig	.024 cc per hour	Begin N_2H_4 Tests
23				.044	
24				.032	
25			150 psig	.036	
26				.035	
27				.024	
28			250 psig	.029	
29				.021	

TABLE VI. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
30	Hydrazine	Ambient	250 psig	.017 cc per hr	Vacuum Bake 24 hrs
31	Nitrogen	Ambient	85 psig	21 scc per hr	
32				21	
33				21	
34				21	
35				21	
36			150 psig	60	
37				60	
38				58	
39				60	
40				61	
41			250 psig	98	
42				95	
43				99	
44				150	
45				97	Final Test

TABLE VII. LEAKAGE DATA

TEST ITEM: HYDRAULIC RESEARCH VALVE/ UPSTREAM SEAT, 103

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	26 scc per hour	
2				25	
3				26	
4				26	
5				25	
6			160 psig	94	
7				93	
8				93	
9				92	
10				92	
11				92	
12			250 psig	156	
13				156	
14				159	
15				159	
16				159	
17				159	
18				149	
19			160 psig	93	
20				93	
21				92	
22				[illegible]	
23				94	
24			85 psig	25	
25				[illegible]	
26				26	
27				25	
28	Nitrogen			27	
29	Hydrazine	Ambient	85 psig	Not Measurable	Begin N_2H_4 Tests
30			160 psig	Not Measurable	
31			250 psig	Not Measurable	
32		250°F	85 psig	Not Measurable	
33			160 psig	Not Measurable	

TABLE VII. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
34	Hydrazine	200°F	250 psig	Not Measurable	Valve Actuated Once
35		Ambient	85 psig	.020 cc per hour	
36				.020	
37				.020	
38				[illegible]	
39				[illegible]	
40			160 psig	.022	
41				.021	
42				.020	
43				.020	
44				.021	
45			250 psig	.025	
46				.022	
47				.022	
48				Not Measurable	
49				[illegible]	
50				[illegible]	
51				.021	
52				[illegible]	
53			185 psig	[illegible]	
54				.020	
55				[illegible]	Vacuum Bake 26 hrs
56	Nitrogen	Ambient	85 psig	Not Measurable	
57			160 psig	[illegible] scc per hour	
58				[illegible]	
59				44	Gas Leakage Erratic
60			250 psig	55	
61				[illegible]	
62				[illegible]	Erratic

TABLE VII. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage sc per hr	Remarks
63	Nitrogen	Ambient	150 psig	[illegible] scc per hour	
64				115	
65				116	Erratic, Increasing with Time; Possible "Wet" Seat/Poppet
					Vacuum Bake 12 hrs
66	Nitrogen	Ambient	85 psig	20	
67				15	
68				21	
69			180 psig	7[illegible]	
70				[illegible]6	
71				7[illegible]	
72			250 psig	1[illegible]	
73				135	
74				1[illegible]5	Final Test

TABLE VIII. LEAKAGE DATA

TEST ITEM: HYDRAULIC RESEARCH VALVE/ DOWNSTREAM SEAT, 103

Test No.	Fluid	Valve Temp °F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
1	Nitrogen	Ambient	85 psig	16 scc per hour	
2				16	
3				16	
4				16	
5				16	
6			180 psig	49	
7				50	
8				50	
9				49	
10				51	
11			250 psig	86	
12				87	
13				87	
14				87	
15				87	
16				[illegible]	
17				86	
18	Hydrazine	Ambient	85 psig	.075 cc per hour	Begin N_2H_4 Tests
19				.075	
20				.069	
21				.053	
22			180 psig	.058	
23				.051	
24				.049	
25			250 psig	.040	
26				.040	
27				.036	
28				.029	
29				.022	
30				.020	
31		200°F	250 psig	.015	
32				.019	Vacuum Bake 18 hrs

TABLE VIII. LEAKAGE DATA (Cont'd)

Test No.	Fluid	Valve Temp ^{o}F	Inlet Pressure ±2 psig	Leakage cc per hr	Remarks
33	Nitrogen	Ambient	85 psig	1175 scc per hour	
34				1169	
35				1154	
36			180 psig	4186	
37				4186	
				4235	
39			250 psig	7385	
40				7200	
41				7385	Final Test

TABLE IX. PERFORMANCE CHARACTERISTICS
PARKER VALVES

PROPELLANT:	HYDRAZINE; 0.0117 LB/SEC @ 14.6 PSID MAX
TEMPERATURE:	
AMBIENT	+35°F TO +250°F
FLUID	+40°F TO +140°F
PURGE	+225°F
OPERATING PRESSURE:	0 TO 300 PSIG
PROOF PRESSURE:	600 PSIG
BURST PRESSURE:	1200 PSIG
OPENING RESPONSE:	7 MSEC MAX @ 24 VDC, 215 PSIG, +250°F
CLOSING RESPONSE:	7 MSEC MAX @ 56 VDC EXT VOLTAGE
REPEATABILITY:	±0.5 MSEC AT 28 VDC, 215 PSIG, 70°F
INTERNAL LEAKAGE:	10 SCC PER HOUR GN_2 @ 300 PSIG
EXTERNAL LEAKAGE:	6 X 10^{-6} SCC PER SEC He @ 300 PSIG
WEIGHT:	0.41 LB MAX

TABLE X. PERFORMANCE CHARACTERISTICS
HYDRAULIC RESEARCH VALVES

PROPELLANT:	HYDRAZINE; 0.0224 LB/SEC @ 28 PSID MAX
TEMPERATURE:	
OPERATING	$35^{o}F$ TO $250^{o}F$
AMBIENT	$-65^{o}F$ TO $250^{o}F$
OPERATING PRESSURE:	335 PSIG
PROOF PRESSURE:	670 PSIG
BURST PRESSURE:	780 PSIG
OPENING RESPONSE:	17 MSEC
CLOSING RESPONSE:	8 MSEC
RESPONSE REPEATABILITY:	1 MSEC OPEN/CLOSE
INTERNAL LEAKAGE:	1 SCC PER HOUR GN_2 @ 300 PSIG, $70^{o}F$
EXTERNAL LEAKAGE:	1 X 10^{-6} SCC PER SEC He @ 300 PSIG
WEIGHT:	0.47 LB MAX

TABLE XI. SUMMARY OF CORRELATION DATA

VALVE IDENTIFICATION	FLUID	LEAKAGE @85 PSIG	LEAKAGE @180 PSIG	LEAKAGE @250 PSIG	REMARKS
PARKER HARD SEAT/102	MIN. GN_2	25	51	74	VAC. BAKE
	MAX. N_2H_4	.044	.040	.053	
	MIN. GN_2	22	48	69	CONTAMINATE
	MIN. GN_2	745	5660	11,219	
	MAX. N_2H_4	.032	.020	.014	ACTUATE
	MAX. N_2H_4			.029	VAC. BAKE
	MIN. GN_2	7466	26,000	45,000	
	MAX. N_2H_4	.017	.068	.340	VAC. BAKE
	MIN. GN_2	756	2036	3273	FINISH
PARKER HARD SEAT/103	MIN. GN_2	125	462	779	
	MAX. N_2H_4	.728	.959	.839	VAC. BAKE
	MIN. GN_2	133	396	672	
	MAX. N_2H_4	.211	.200	.246	10,000 CYCLES
	MAX. N_2H_4	.189	.141	.028	VAC. BAKE
	MIN. GN_2	99	300	514	STORAGE
	MIN. GN_2	101	277	419	CONTAMINATE
	MIN. GN_2	522	1525	2504	
	MAX. N_2H_4	.025	.025	.040	VAC. BAKE
	MIN. GN_2	2093	4737	6006	
	MAX. N_2H_4	.032	.020	.063	VAC. BAKE
	MIN. GN_2	2432	6429	10,050	FINISH
HYDRAULIC RESEARCH 102 UPSTREAM SEAT	MIN. GN_2	4.0	11	18	ACTUATE
	MAX. N_2H_4	0	0	0	VAC. BAKE
	MIN. GN_2	7.0	19	26	FINISH
HYDRAULIC RESEARCH/102 DOWNSTREAM SEAT	MIN. GN_2	2.8	7.5	12	100 CYCLES
	MAX. N_2H_4	0	0	0	VAC. BAKE
	MAX. N_2H_4	.044	.039	[illegible]	VAC. BAKE
	MIN. GN_2	21	58	97	FINISH
HYDRAULIC RESEARCH/103 UPSTREAM SEAT	MIN. GN_2	25	92	149	VAC. BAKE
	MAX. N_2H_4	0	0	0	ACTUATE
	MAX. N_2H_4	.029	.022	.025	VAC. BAKE
	MIN. GN_2	18	76	133	FINISH
HYDRAULIC RESEARCH/103 DOWNSTREAM SEAT	MIN. GN_2	16	49	94	
	MAX. N_2H_4	.075	.058	.096	VAC. BAKE
	MIN. GAS	1154	4165	7200	FINISH
PARKER TEFLON SEAT 102	MIN. GN_2	15	29	32	
	MAX. N_2H_4	0	0	0	12,000 CYCLES
	MAX. N_2H_4	0	0	9	VAC. BAKE
	MIN. GN_2	6	13	19	FINISH
PARKER TEFLON SEAT 103	MIN. GN_2	25	51	51	
	MAX. N_2H_4	.044	.040	.072	VAC. BAKE
	MIN. GN_2	20	46	53	FINISH

REFERENCES

1. Marr, J.W., The Fundamentals of Leakage Phenomena (A State of the Art Report) General Electric Company, 1965.

2. Greer, H., Correlation of Liquid-Gas Leakage in a Hard-Seat Propellant Valve, The Aerospace Corporation, December 1970.

3. Burke, W.K., Reaction Engine Module, Monopropellant Investigation of Thrust Chamber Valve Liquid-Gas Leakage Rate Correlation, Rocket Research Corporation, June 1970.

4. Santler, D.J. and Moller, T.W., "Fluid Flow Conversion in Leaks and Capillaries," Vacuum Symposium Transactions, 1956.

5. Doebler, R.L., Leak Testing of Satellite Liquid Propellant Valve Seals, SAMSO TN 35-70-30, The Aerospace Corporation, February 1971.

6. Poiseuille, J.M., Compt. Rend., 11, (1840) 12, (1841) 15, (1842).

7. Perry, R.H., Chilton, C.G., Kirkpatrick, S.D., Chemical Engineers Handbook, Fourth Edition, McGraw Hill Publishing Company, 1963.

8. Weiner, R.S., Basic Criteria and Definitions for Zero Fluid Leakage, NASA Technical Report No. 32-926, December 1966.

9. Salvinski, R.J., Advanced Spacecraft Valve Technology Compilation, Volume I, TRW Systems Group, July 1970.

10. Tellier, G.F., and Lewellen, J.R., Poppet and Seat Design Criteria for Contaminant-Particle Resistance, Rocketdyne Division, North American Rockwell Corporation, April 1970.

11. Proeschel, R.A., Experimental Study of Hydrazine Propellant Valves for Long Duration Planetary Missions, Space Division, North American Rockwell Corporation, September 1972.

AUTHOR'S BIOGRAPHY

GARRETH J. GUNDERSON, SSgt, USAF.

BS Degree, Chemical Engineering, North Dakota University, 1969.

MBA Degree, Management, Golden Gate University, 1972

Project Engineer, Engine Components Branch, Liquid Rocket Division.

In addition to the valve leakage program just completed, SSgt Gunderson has been engaged in dynamic material compatibility problems associated with high energy propulsion systems, and the AFRPL Transtage ACS Valve Storage Test Program.

SSgt Gunderson is a member of the American Institute of Chemical Engineers and Sigma Tau.